BANKING OF FIRES
WITH A
GREEN CHAIN GRATE STOKER

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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Economical Banking of Fires
with a green chain grate

ECONOMICAL BANKING OF FIRES
WITH A
GREEN CHAIN GRATE STOKER

A THESIS

PRESENTED BY

J. J. HAYES, JR.
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INTRODUCTION.

The object of this thesis is to find the most economical way of banking fires with the Green chain grate stoker installed in the power plant of the Armour Institute of Technology. No attempt has been made to carry out the tests,that have been made,with that accuracy required in obtaining heat balances; instead the data collected is merely that of commercial tests in which the most important stress has been laid on those factors relevant to economical operation.

It might be best to first give the essence of those factors. Economy, in shutting down a boiler, considering the coal end alone, would be best attained by allowing the fire under the boiler to go out during the period in which no steam is wanted from that unit and building a new fire when it is desired that that unit furnish steam. Unquestionably this method would be the best for a small plant with a short operating period. If, however, we take into consideration the amount of water evaporated during the period in which the fire is banked and the amount of attendance needed during the bank,along with the coal burned, we have a very complex problem. Furthur it would be of

advantage to use that method of banking which would enable the boiler to came up to its capacity in as short a time as possible after breaking up the bank. This last condition would be of prime importance in central stations, where a number of boilers are kept banked ready for the peak loads. In such plants, where there is always some demand for steam, the water evaporated by a boiler while banked would be of use; whereas in the small isolated plant, having a period in which there is no demand for steam, the evaporation of water is undesirable, except for maintaining the boiler pressure. In both types of plants, that method of banking which requires the least amount of attendance would undoubtably be in favor. To summarize - the most economical method of banking fires would be that in which the least amount of coal is used with the least amount of labor, while at the same time the boiler setting is kept sufficiently warm to enable the boiler to come up to capacity in as short a time as possible after breaking up the bank.

The cost of coal and of labor during the banking period is a standby loss to any steam power

plant, and is a large factor in decreasing the overall efficiency of the plant. The number of boilers in any central station that are kept banked,to be ready for the peak loads,shows the importance of banking economically. Even in small plants, the decrease in efficiency caused by burning coal needlessly during the banking period is appreciable, and amounts to a considerable sum yearly.

The variation in the length of banking period, in the cost of coal and of labor, in the design of boiler settings and furnaces, and the numerous variations in operating conditions among power plants, limit the application of an economical method of banking to one particular plant. In other words, the proper way of banking his fires is a problem the operating engineer must solve for himself. However, there are enough points of similarity in the good methods of banking fires on chain grate stokers to make the results of tests on one of value to the operators of corresponding types. It is, therefore, hoped that the results of this thesis will be of such a value.

DESCRIPTION OF STOKER.

The stoker, upon which the tests for this thesis were carried out, is a chain grate automatic stoker manufactured by the Green Engineering Company. Two large cast iron side frames and several bracing and stiffening rods, beams,and girders, form the framework. Upon this are placed roll shafts, the upper ones having center support. At the front and rear of the framework are shafts upon which a number of sprockets are carried. The front sprocket shaft has a gear at each end by which the stoker is driven. Upon the roll shafts are heavy cast iron links,mounted in alternate rows on shafts, and forming an endless chain around the sprocket shafts. These links have thoroughly ventilated and substantial heads, which form the actual firing surface. A defective link is easily replaced while the stoker is in operation. The driving links engage the sprockets at either end. The front sprocket shaft is driven by the movement of an adjustable rocker arm, which with a ratchet and pawl attachment causes rotation of the gears on the sprocket shaft through a train of gears.

Over the front of the grate is a coal hopper,

which when filled holds a little over half a ton. The movement of the grate, about four inches per minute under the average load, carries the coal past an adjustable gate which regulates the depth of fuel bed. This feed gate is lined on the inside with tile and on the outside has a shield so placed as to form a ventilated air chamber between the tile and the coal hopper, this construction being effective in preventing the fire from eating back into the coal hopper.

The whole weight of the stoker rests upon two truck shafts supported by car wheels on two small gauge tracks. This enables the stoker to be moved intact away from the boiler setting for repairs. All parts of the stoker are easily accessible and any defective member is quickly renewed.

The stoker front extends two feet in front of the boiler front. For an idea of the construction of the stoker, reference should be made to the drawing of the boiler setting.

The stoker is driven by a three horse power vertical steam engine,controlled by hand. This engine is belted to a jack shaft, and an eccentric on this,moves the rocker arm that drives the stoker. The speed of the grate may be anything desired.

DESCRIPTION OF BOILER AND SETTING.

The Stirling boiler used in connection with this stoker is the largest of five located in the power plant of the Armour Institute of Technology. This boiler, type"F", consists of three steam drums and one mud drum connected by rows of 3¼ inch lap welded, mild steel tubes, so constructed as to enter the drums radially. All of the steam drums are connected by steam tubes; the first two are joined with tubes below the water level. Each drum is 3'- 6" in diameter and 12'- 6" long with shell of 9/16" and heads of 3/4" flange steel. The longitudinal joint of the drums is a lap joint double riveted. The total number of water tubes is 263. The number of steam tubes is 20. The heating surface of the boiler is approximately 3500 square feet; which, if an allowance of ten square feet per boiler horse power be made, gives the boiler a rating of 350 h.p.

The boiler is equipped with a GECO pressure waterback. This consists of two extra heavy 5½" pipes extending across the rear end of the grate under the overhang of the bridgewall. The front pipe connects at one end with a water tube leading to the front steam drum. In a similar manner the

rear pipe connects with a 3½" tube leading to the mud drum. (Note: See drawing of the boiler setting for the detail of this construction.) When the boiler is in operation there is a continuous flow of water from the mud drum through the waterback to the front steam drum.

The feed water to the boiler enters the rear upper drum and flows down to the mud drum. It then circulates through the water tubes to the front steam drums. Steam is drawn off the middle upper drum on which are also two 3½" safety valves, which blow off at 125 pounds pressure. The blow off pipe is connected to the bottom of the mud drum. The pipes leading to the gauge glass are connected to the middle steam drum. In one end of each drum there is a manhole, which can be removed for the cleaning and inspection of the boiler.

The boiler is incased in a brick setting, the interior of which is lined with No.1 fire brick. The overall dimensions are length 18'-3", width 13'-0", and height 18'- 5½". Both side walls are 18", the rear wall 13" in thickness. The boiler is not supported by the brickwork but is held up by the

steam drums resting on wrought iron beams carried by wrought iron columns, which rest on foundations made of cast iron. The mud drum is supported only by the water tubes from the steam drums, enabling free movement of the tubes for expansion and contraction. In one side wall there is a 14"x 16" inspection door, and ~~the~~ in the rear wall are eight doors for the removal of soot. The boiler is equipped with a Vulcan soot blower, which keeps the outside of the tubes clean.

The furnace - a smokeless one for the kind of coal used - was designed by the Green Engineering Co. As the green fuel leaves the coal hopper and passes under the gate it receives the heat reflected by a flat ignition arch, 4'- 6" in length, which becomes incandescent after the boiler has run for a short time. This causes the distillation of the volatile matter from the coal and aids materially in causing these gases to ignite. Should the fuel be thrown into the furnace at too great a rate, the distillation of the volatile will be of such rapidity that smoke will be produced. By looking in the peephole in the sidewall just back of the gate the fireman can tell if the coal is being

thrown into the furnace too rapidly. As the grate continues its movement the coal ignites, burning with a flame that ordinarily extends over to the first row of tubes. To furthur increase the mixing of the gases, and at the same time maintain the high temperature required for their combustion, a sprung arch, 7'- 7" above the grate, extends from the flat ignition arch to within 18" of the first row of tubes. With this arch construction the furnace is smokeless when operated properly.

By the time the coal has reached the bridgewall it is practically burned out, although still white hot. This hot ash, coming so close to the waterback, causes a high evaporation to take place in the latter. In this way a saving in heat is effected which would otherwise be lost if the ash were allowed to drop into the ash pit while hot. The relatively cool ash falls from the end of the grate into an air tight ash pit. The fine coal that falls through the grate is collected and passed into the hopper again. The ash is removed by raising the sheet iron partition and hoeing out the refuse.

The path of the hot gases from the furnace is

traceable on the drawing of the boiler setting. The fire brick baffles are so placed as to constrain the gases into passing up the first set of tubes, down the second, and up the third. With this construction the gases are brought into intimate contact with the tubes of the boiler, and with the good scrubbing action that takes place a high efficiency of the boiler is easily attainable.

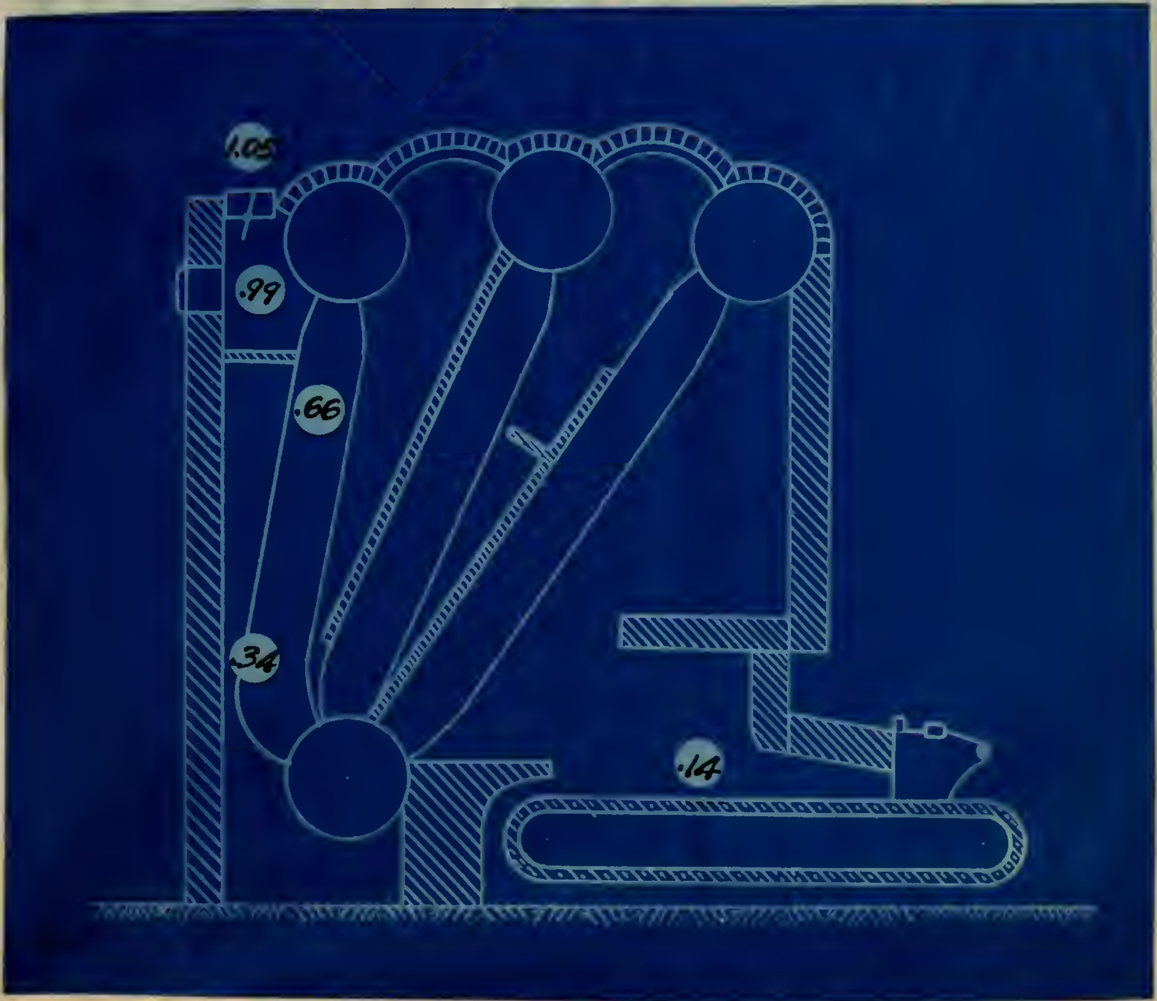
The draft for the furnace is produced by a 175 foot brick stack of 38.5 square feet area. This stack is situated at the back of the boiler, and the breeching leads from it directly to the damper located back of the rear upper drum of the boiler. This damper being warped did not give sufficient regulation of draft in the tests that have been carried out. In order to cut down the draft over the fire, some of the doors in the rear wall of the setting were opened, thus short circuting the flow of gases. The influence of the damper is shown on sketches (2) and (3).

The coal used in the furnace was No. 2, Buckhorn Kentucky washed nut, with the following proximate analysis:

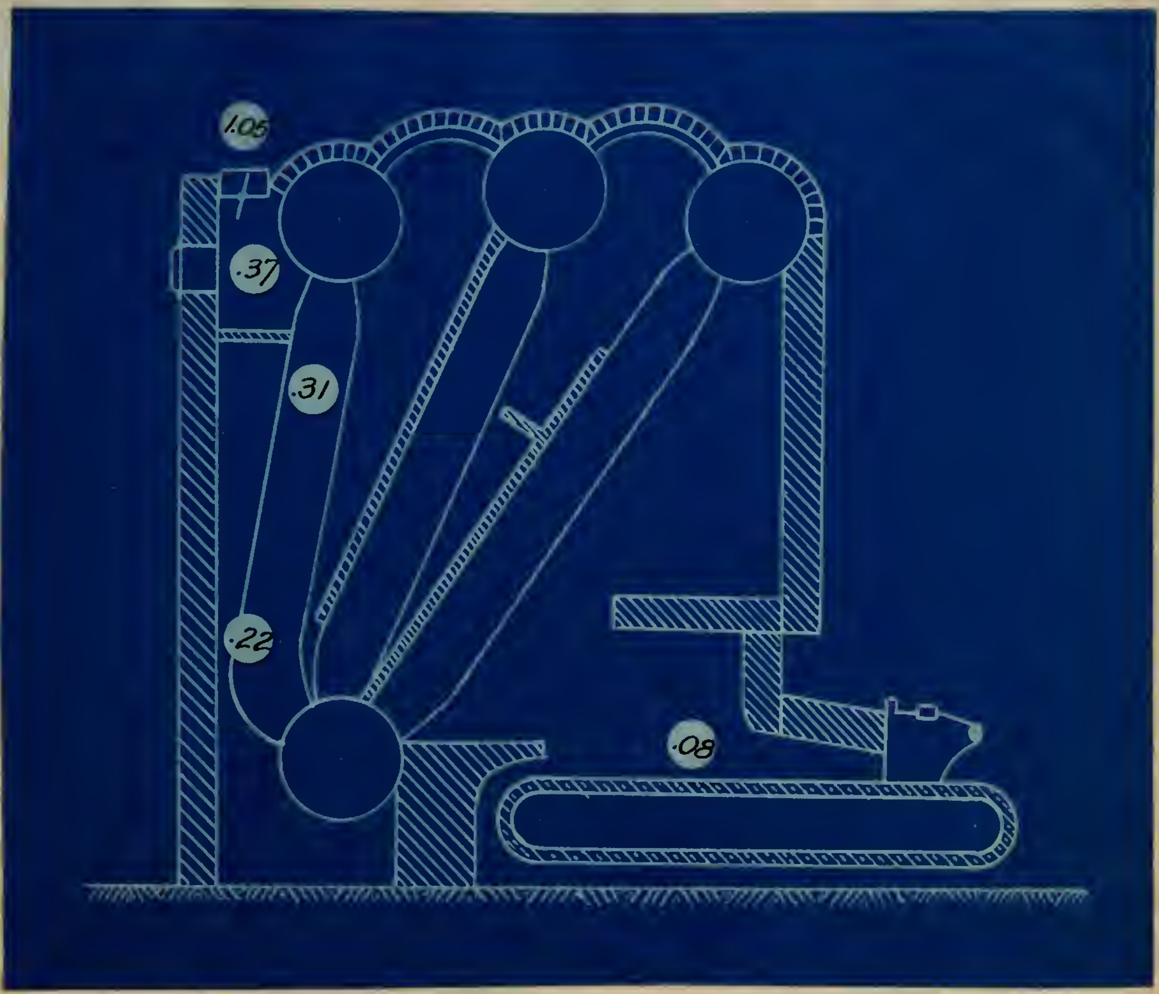
Moisture 6.5 Volatile Matter 50.4
Ash 7.6 Fixed Carbon 35.5
B.T.U. 13,500.

That this coal is suitable for burning in this type of furnace is shown in the fact that at 50% overload there was but 15% combustible in the ash, on the average 13% CO_2, and a combined boiler and furnace efficiency of 72%, with smokeless combustion.

The ease with which the chain grate stoker is controlled is beyond question. The feed gate, supported from a heavy square shaft between vertical guides, is adjustable by a worm and sector attachment on the side frame, opposite the driving mechanism, and may be readily raised or lowered to vary the thickness of fuel bed. With the adjustable rocker arm and variable speed engine the movement of the grate is absolutely under the control of the fireman. The design of the grate is such that a minimum of air leakage takes place, as shown by the flue gas analysis, yet there is no smoke. In operating there is no need to open any door in the furnace thereby giving a uniform temperature



SKETCH (2)
DRAFTS WITH DAMPER OPEN.



SKETCH (3)
DRAFTS WITH DAMPER CLOSED.

and a high efficiency in the furnace. The grate is self cleaning, and yet of such simple construction that it cannot but be classed as one of the best on the market.

The saving in heat, as effected by the water-back, has already been touched upon. Suffice it to say that the installation of this device caused a saving of 15% in the coal consumption.

This Stirling boiler is a very successful generator of dry steam. As all of the tubes enter the steam drums, disengagement takes place at a low velocity, which insures a dry steam. The circulation through the tubes is, however, of sufficient velocity to prevent the formation of scale on the tubes; instead it collects at the bottom of the mud drum and is removed by blowing off the boiler. Since the tubes are in parallel, four rows deep, there is never need for destroying more than one tube in replacing a defective one.

One defect in the boiler is the surging of water that takes place in the tubes leading to the front steam drums, which, since the tubes to the gauge glass are connected to the middle drum,

causes an incorrect indication of the mean water level on the boiler.

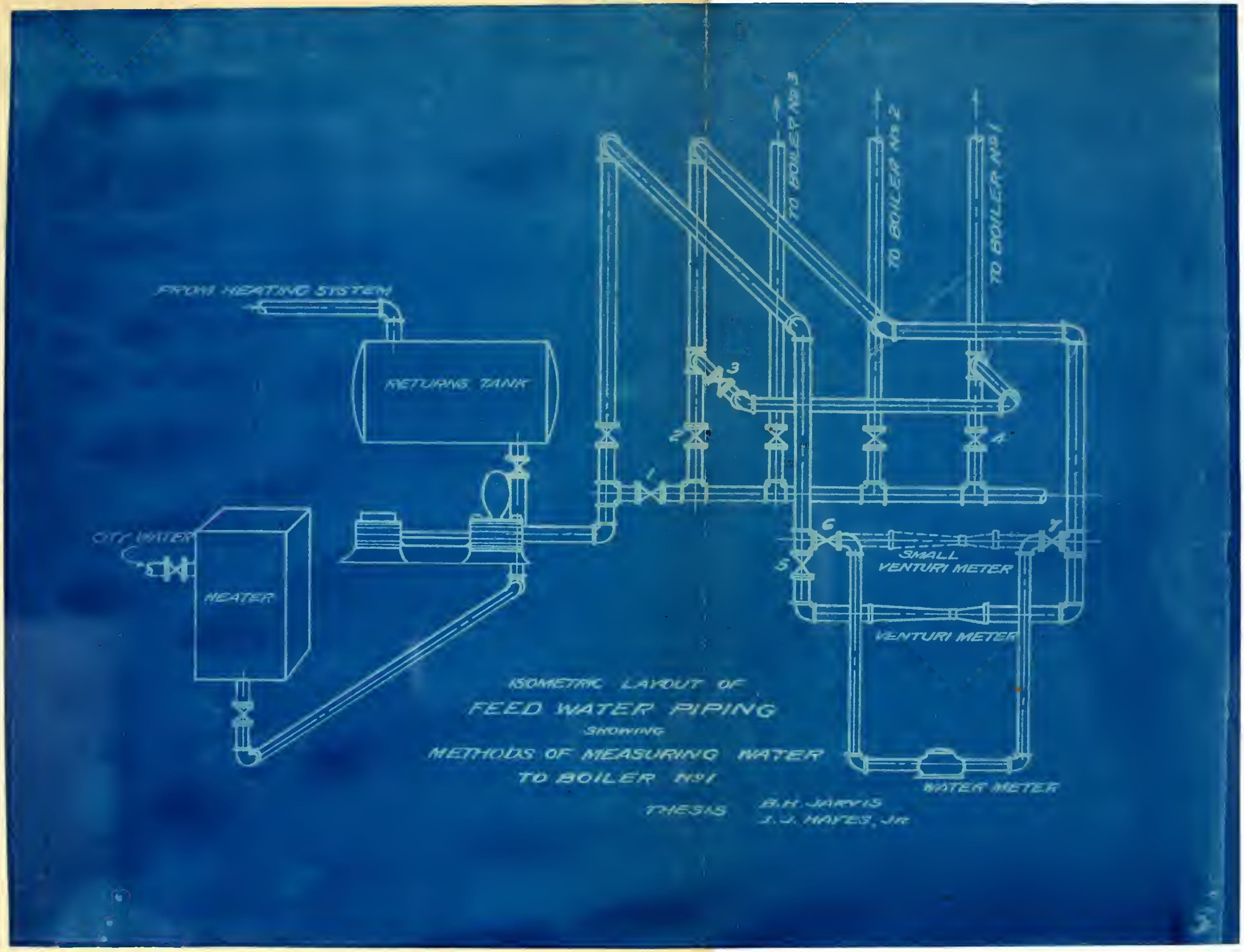
An explanation might be given for the exceptional draft conditions as shown by sketch (2). In the first place, the usual draft over the fire for a grate of this type, burning 25 pounds of coal per square foot of surface per hour, is from .25 to .30 inches of water. Since draft is merely a measure of the resistance offered to the flow of the gases, on examining the uniform size of the coal used it could be understood that this resistance over the fire was small. Furthurmore, from the same sketch a throttling effect of the gases could be seen between the upper rear drum and the rear baffle plates. In lowering these baffle plates the loss of draft here could be eliminated, but in so doing the flow of air through the fuel bed would be excessive, as the damper was not in proper working order. Since under these conditions the boiler made all of the steam required, no change was made in the position of the baffle plates, although in commercial practice this probably would have been done.

Description of Auxiliary Appartus.

The source of feed water to the boiler is the returns from the heating system of the Institute buildings and the Armour flats- a square block of three and four story apartment buildings- the total heating surface being about 1,250,000 square feet. The temperature of this condensate as it comes to the returns tank is on the average 205°F., which is too high to warrant raising its temperature furthur before entering the boiler. The make up water is taken from the city mains and is first run through a Webster open heater of the induced type. Here most of the scale forming elements are deposited, and the temperature of the water is raised to 210 F. The water is pumped from the returns tank by a Smith & Valle duplex pump of 200 gallons capacity per minute.

The arrangement of the feed water piping is shown in sketch (1). For measuring the flow of water to the boiler under test, three methods were used. The first was a large venturi meter installed as shown. This was a recording meter manufactored by the Builders Iron Foundry Co. and besides plotting the rate of flow on a circular chart an integrating device metered the flow in thousands of

SKETCH (1).


FROM HEATING SYSTEM
RETURNING TANK
CITY WATER
HEATER
TO BOILER No 3
TO BOILER No 2
TO BOILER No 1
1
2
3
4
5
6
7
SMALL VENTURI METER
VENTURI METER
WATER METER
ISOMETRIC LAYOUT OF
FEED WATER PIPING
SHOWING
METHODS OF MEASURING WATER
TO BOILER No 1
THESIS
B.H. JARVIS
J.J. HAYES, JR.

SKETCH (1).

pounds. As ordinarily operated this instrument recorded the total water flowing to all of the boilers, valves 1,3,6,and 7, as indicated in sketch (1) being closed, and valves 2 and 5 open. In order to have it record the water flowing to Boiler No.1, which was under test,valves 1 and 3 were opened and valves 2 and 4 closed. Although this large venturi meter was accurate to a thousand pounds, the water evaporated during a bank was of such a small quantity as to demand a more delicate method of measurement. A smaller venturi was next installed, as shown in dotted lines in the sketch. The feed water was run through it and a mercury manometer indicated the flow; the quantity of water being obtained from a calibration curve of the instrument. Although this method was more accurate than the former,there was still some error- due to the various rates of flow, the pulsation of the pump, and the limit to the amount of water that this meter could handle. As an experiment two pressure gauges were installed in place of the manometer, and proved totally incorrect in their indications. The last method used was a water meter

of the revolving disk type, which registered the flow in cubic feet of water. Some trouble was experienced in having this meter pick up at first, but in its use it proved to be more accurate than any of the other methods.

The water meter was calibrated at a flow equal to the average flow of water during a test. Two determinations of the slip showed that the meter registered just 97.09 per cant of the actual flow. The amount of water used during a test was found by correcting for this error.

A Jena glass thermometer(0-300 F.) was used to measure the temperature of the feed water. The calibration curve of this instrument is shown later and was found by finding the error at 32° and at 212° and drawing a straight line through these points as plotted.

A standard Bourdon gauge manufactured by the American S.G.& V.Co. was used in connection with the tests to give the steam pressure. The calibration curve of this is shown later. All the readings given in the log sheets have been corrected for the error in this gauge.

A recording pressure meter gauge manufactured by the American S.G.& V. Co. was also used, the pressure of the steam being automatically plotted against the time on a circular sheet. Comparison of this instrument with the corrected readings of the Bourdon gauge showed it was correct above 30 pounds pressure. A chart from this instrument is included in the report.

Charts from a Bristol recording pyrometer, which indicated the temperature of the flue gas, were collected merely as a matter of interest. The temperatures as indicated are much to high and the chart included with the data is merely to give an idea of the relative changes in the flue gas temperature that takes place during a banking period.

A recording temperature instrument of the feed water was disregarded due to the limitations of the readings of the imstrument and to the large per cent of error in the indications.

Two draft gauges, calibrated in inches of water, manufactured by the Ellison Draft Gage Co. were used. One was fixed near the inspection door of the furnace, so that a pipe inserted through a

hole in same and connected by a rubber tube to the gauge enabled it to give the correct drop in pressure between the outside and inside of the furnace,since no door was opened to insert the pipe. The other draft gauge was attached to a movable stand which could be carried wherever desired.

A Fairbanks scale of 1000 lbs. capacity was used to weigh the coal in a bushel basket. Before each test the scale beam was adjusted to balance correctly at 60 pounds weight. As the weight of the basket and 60 pounds of coal amounted to 68 pounds, the scale was assumed to be correct at this point, although calibrated at a slightly lower point.

A standard Orsat flue gas apparatus was used. For a description of this insrtument and its operation see Carpenters Experimental Engineering, P 482. Fresh solutions were made each test that this instrument was used. All samples for the analysis were extracted from the top of the third pass of the boiler.

PROCEDURE.

Before proceeding with the thesis proper, the operating conditions of the stoker and boiler were investigated. Draft readings were taken with the damper opened and closed, the results being shown in sketches (2) and (3). The per cent of combustible in the ash was found to be but 15.2%, which is exceptionally low. An analysis of the flue gas was taken and showed 12% CO_2. A short efficiency test was run on the boiler, the feed water, coal, and ash being weighed, temperature of feed water and steam pressure being recorded. As this data is of no importance to the subject of this thesis, it was not included with it. It is, however, of interest to know that from this short test the boiler and furnace were found to be giving good efficiencies, the overall efficiency of both being 71% at about 50% overload.

Testing.

In all of the tests that were carried out the following procedure was in order:

PRELIMINARY TO THE TEST

while boiler was being worked at its average load; which was about 50% overload in all cases

(1) The tubes were blown with the soot blower and the boiler and gauge glass were blown off.

(2) Clean charts were placed on the recording pressure gauge and pyrometer.

(3) The valves in the feed water line were adjusted so that the meter registered only that fed to boiler No. 1.

(4) The depth of fuel bed was measured at the gate.

TEST BEGUN

as near as possible to a half hour before the boiler was to be shut down.

Readings were taken at 15 minute intervals of the following:

Time

Pressure

Water Meter

Feed Water temperature

Outside temperature

Drafts

Also condition of fire, damper, and setting noted.

Movement of Stoker stopped.

From this point on the above readings were taken at 15 minute intervals till the variations in them became small, then the readings were taken at half hour and hour intervals. The time, amount, and

condition of the coal, and the method of putting it in the furnace, were noted whenever fuel was added to the fire.

A string was placed on the gauge glass one half hour after the stoker had been stopped.

Stoker Started

The coal hopper was filled and the amount of coal added to keep it filled till the boiler had worked up to capacity was recorded.

Readings taken as before every fifteen minutes.

The test was ended when, with live steam turned into the heating system, the boiler was able to maintain 85 pounds pressure. At this point the water level in the gauge glass was brought to the string and the meter was read.

RUN No. 1.

ARMOUR INSTITUTE METHOD

FEB. 21-22, 1913
7.58 HOURS

BAROMETER, 29.73".

TIME.	WEIGHT WATER LBS.	FEED WATER TEMP. °F	STEAM PRESS. LBS./□"	DRAFTS In. H_2O			REMARKS.
				OVER FIRE.	UNDER DAMPER	BASE STACK.	
P.M.	WEIGHT OF WATER UNKNOWN.						STOKER STOPPED. DAMPER CLOSED
10:00		–	82	.04	.13	.90	6" FIRE.
10:30		–	72	.04	.12	.86	
10:45		–	66	.02	.12	.82	
11:00		–	75	–	–	–	DAMPER OPEN
11:15		–	75	.02	.15	.65	DAMPER CLOSED
11:30		–	60	.02	.18	.77	
11:45		–	60	.02	.19	.75	
12:00			55	.02	.16	.72	
A.M.							540.1# COAL FIRED
1:00			38	.05	.46	.65	GATE OPEN. DAMPER OPEN
2:00			20	.03	.44	.65	DAMPER CLOSED.
3:00							STOKER STARTED HOPPER FILLED.
4:00							
4:30			85				2072# COAL FIRED TO REACH FULL LOAD.

RUN No. 2.

ARMOUR INSTITUTE METHOD. (IMPROVED)

FEB 22-23 1913
5.66 HOURS.

BAROMETER 29.67

TIME.	WEIGHT WATER LBS.	FEED WATER TEMP. °F	STEAM PRESS. LBS./□"	DRAFTS In. H_2O			REMARKS.
				OVER FIRE	UNDER DAMPER	BASE STACK.	
P.M. 10:30	WEIGHT OF WATER UNKNOWN	—	80	.03	.15	.84	STOKER STOPPED, 6" FIRE, FULL DRAFT GATE OPEN.
11:00		–	90	–	–	–	WATER LEVEL RECORDED.
11:45		–	65	–	–	–	DAMPER CLOSED
12:00		–	55	–	–	–	224# COAL FIRED GATE OPEN
A.M. 1:00		–	50	–	–	–	
1:45		–	47	–	–	–	112# COAL FIRED
2:30		–	44	–	–	–	STOKER STARTED. HOPPER FILLED. DAMPER OPENED
4:10		–	80	–	–	–	1450# COAL FIRED TO REACH FULL LOAD.

RUN No.3.

GREEN ENGINEERING CO.
METHOD.

MAR 14-15. 1913.

BAROMETER 29.81". 7.58 HOURS.

TIME.	WEIGHT WATER LBS.	FEED WATER TEMP. °F	STEAM PRES. LBS/□"	DRAFTS In. H_2O			REMARKS.
				OVER FIRE.	UNDER DAMPER	BASE STACK.	
P.M.							
9:20	WEIGHT OF WATER UNKNOWN.	-	90	.13	.80	.92	STOKER STOPPED 8" FIRE
10:00		-	85	.15	.81	.92	DAMPER CLOSED.
10:30		-	80	.05	.17	.90	
10:45		-	80	.02	.14	.89	
11:00		-	80	.03	.14	.90	981# WET COAL AND DRIPPINGS FIRED.
11:30		-	75	.03	.15	.91	
12:00		-	71	.02	.13	.86	
AM							
1:00		-	56	.02	.12	.86	
2:00		-	26	.02	.12	.85	
3:00		-	15	.02	.12	.85	
3:54		-	10	.02	.11	.82	STOKER STARTED
4.45		-	85	.12	.73	.89	1360# DRY COAL TO REACH FULL LOAD.

RUN No 4

GREEN ENGINEERING CO. METHOD.

BAROMETER 29.76".

MAR. 20-21, 1913.
7.18 HOURS.

TIME.	WEIGHT WATER LBS.	FEED WATER TEMP. F.	STEAM PRES. LBS/□"	DRAFTS IN. H_2O			REMARKS.
				OVER FIRE.	UNDER DAMPER	BASE STACK.	
P.M.							
10:00	WEIGHT OF WATER UNKNOWN	–	93	11	.82	.95	STOKER STOPPED 6" FIRE.
10:15		–	96	.10	.80	.96	
10:30		–	90	.09	.78	.92	
11:00		–	75	.08	.77	.90	
11:15		–	73	.10	.81	.97	
11:30		–	63	.10	60	.96	
11:45		–	75	.03	21	70	930# WET COAL, 186# DRIPPINGS FIRED; DAMPER CLOSED.
12:00		–	80	.04	.23	.74	
A.M.							
1:00		–	60	.02	.19	.61	
2:00		–	37	.03	.20	.63	
3:00		–	18	.03	.21	.64	
4:00		–	13	.02	.13	.60	STOKER STARTED
5:00		–	85	.05	.63	.60	1612# COAL FIRED TO REACH FULL LOAD.

RUN No 5.

ARMOUR INSTITUTE METHOD.

MAR 31 - APR 1, 1913
7.75 HOURS.

BAROMETER 29.90"

TIME.	WATER METER CU. FT.	FEED WATER TEMP. °F.	STEAM PRES. LBS/□"	DRAFTS IN. H_2O.			REMARKS.
				OVER FIRE.	UNDER DAMPER	BASE STACK	
P.M.							
9 30	665	136	62	11	.61	.95	FULL LOAD
9 45	736	137	98	11	.61	.95	STOKER STOPPED, 6" FIRE, DAMPER AND GATE OPEN.
9 57	751	131	-	-	-	-	
10 00	760	166	90	.09	.60	.88	
10 15	821	166	77	.08	.55	.82	
10 30	840	153	77	.08	.55	.78	DAMPER CLOSED.
10 45	871	148	74	.03	.25	.75	
11 00	875	144	70	.04	.25	.76	
11 15	-	-	67	.04	.25	.75	
11 30	-	-	85	.04	.25	.73	420# COAL FIRED.
11 45	876	140	70	.035	.25	.70	
12 00	-	-	64	.04	.25	.70	
A.M.							
12 15	-	-	57	.04	.25	.70	420# COAL FIRED
12 30	880	140	50	.04	.28	.58	
1 30	-	-	25	.04	.28	.58	
2:30	881	123	20	.04	.28	.58	
3 30	925	86	10	.04	.29	.59	
4:00	-	-	6	.06	.47	.56	DAMPER OPENED, STOKER STARTED.
4 30	943	67	5	.08	.47	.56	
5:00	-	-	32	.06	.47	.56	
5:15	964	155	65	.08	.53	.77	1440# COAL FIRED TO REACH FULL LOAD.

RUN No. 6.

ARMOUR INSTITUTE
METHOD (IMPROVED)

APR 1-2, 1913
7.5 HOURS

BAROMETER 29.20"

TIME.	WATER METER CU. FT.	FEED WATER TEMP. °F.	STEAM PRES. LBS/□"	DRAFTS in. H_2O OVER FIRE.	DRAFTS in. H_2O UNDER DAMPER.	DRAFTS in. H_2O BASE STACK.	REMARKS.
P.M.							
9:45	76	198	92	.11	.62	.84	FULL LOAD.
10:00	102	179	84	.05	.63	.83	STOKER STOPPED 6" FIRE.
10:15	137	170	92	.05	.63	.83	
10:30	151	154	80	.08	.57	.82	
10:45	172	137	75	.08	.57	.81	
11:00	–	–	80	.08	.57	.81	
11:15	–	–	74	.03	.18	.77	DAMPER CLOSED.
11:45	–	–	73	.03	.18	.77	
12:00	–	–	70	.06	.26	.75	840# COAL FIRED PILED HIGH UNDER ARCH. GATE SEALED.
A.M.							
12:30	191	152	56	.06	.26	.75	
1:30	–	–	35	.06	.26	.75	
2:30	–	–	20	.06	.26	.69	
3:30	–	–	15	.00	.26	.65	
3:50	–	–	6	–	–	–	STOKER STARTED.
4:00	–	–	6	.08	.47	.57	
5:00	206	88	60	.09	.61	.75	
5:15	–	–	75	.08	.62	.81	1550# COAL FIRED TO REACH FULL LOAD.

RUN No 7.

GREEN ENGINEERING CO.
METHOD

APR 2-3, 1913.
9.0 HOURS.

BAROMETER 29.20

TIME.	WATER METER CU. FT.	FEED WATER TEMP. F	STEAM PRES. LBS/□"	DRAFTS IN H_2O			REMARKS.
				OVER FIRE	UNDER DAMPER	BASE STACK	
P.M.							
9:00	201	128	91	.08	.61	.78	STOKER STOPPED
9:20	205	130	93	.08	.61	.76	
9:45	207	164	80	.07	.55	.70	
10:00	213	136	81	.06	.53	.69	
10:30	236	135	80	.04	.28	.69	DAMPER CLOSED.
10:45	–	–	–	.02	.28	.71	
11:00	–	–	–	–	–	–	600# COAL, 13# DRIPPINGS FIRED; THICK FIRE; GRATE CLOSED
11:15	245	126	52	.06	.28	.67	
11:30	–	–	52	.06	.28	.67	
A.M.							
12:30	265	130	50	.06	.28	.65	
1:30	–	–	35	.05	.28	.65	
2:30	–	–	20	–	–	–	
3:15	–	–	3	.04	.21	.41	300# COAL FIRED.
3:30	318	57	0	.04	.21	.41	
4:00	332	59	0	.04	.21	.41	
5:00	–	–	3	.06	.22	.49	
5:30	341	140	34	.06	.45	.55	
5:45	–	147	48	.08	.47	.52	
6:00	–	–	85	.08	.51	.71	1532# COAL FIRED TO REACH FULL LOAD.

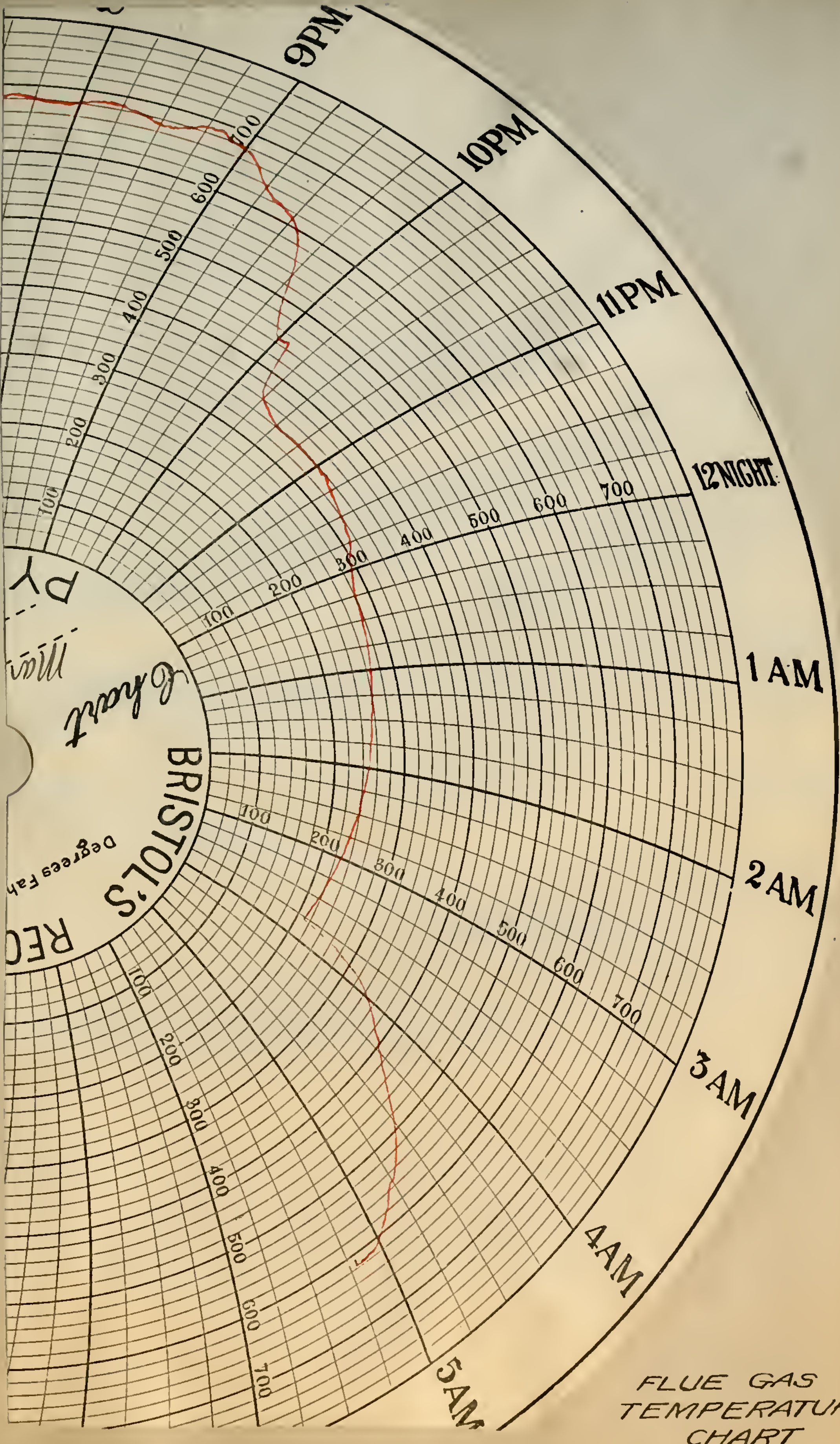
RUN. No. 8.

GREEN ENGINEERING CO.
METHOD.

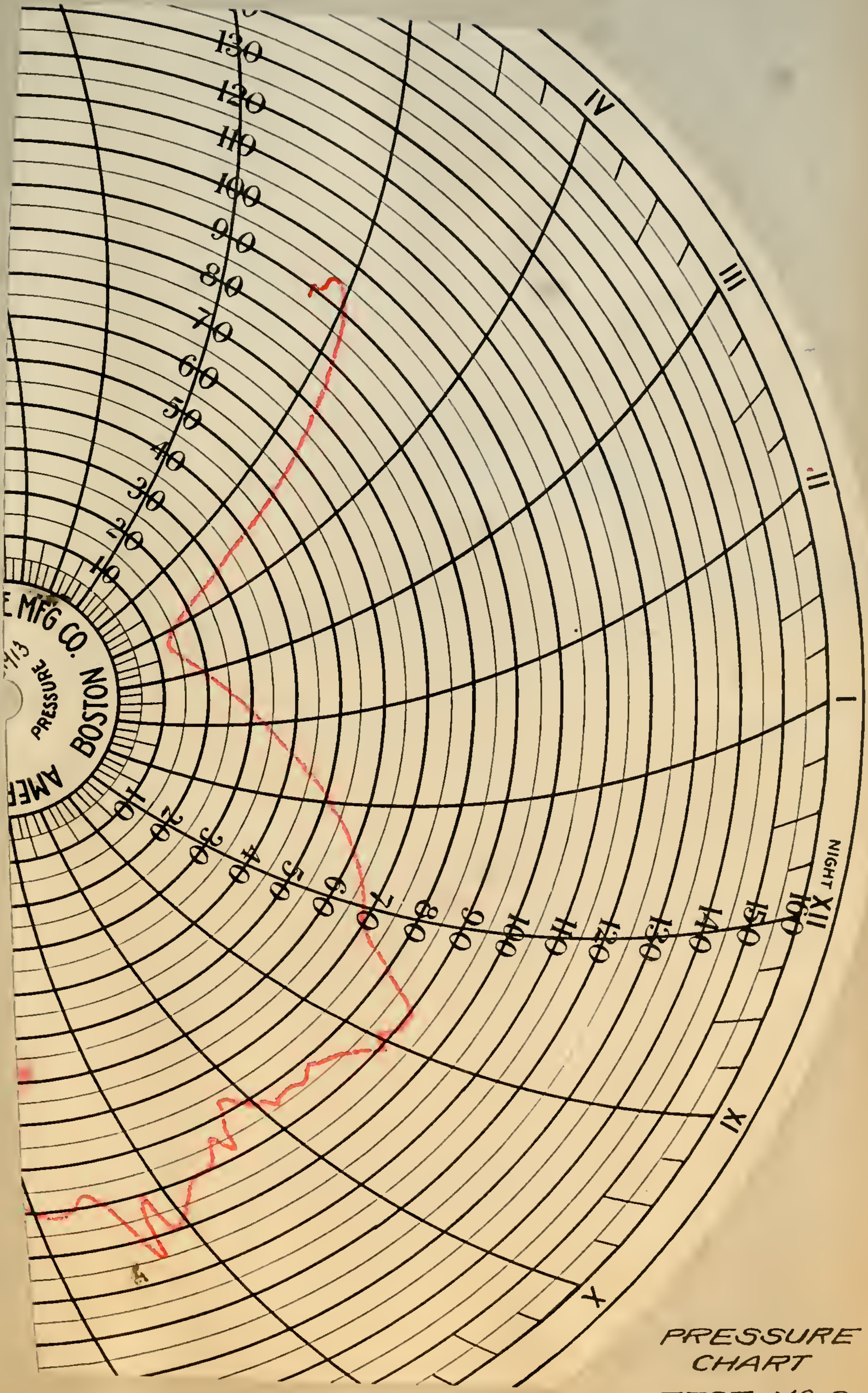
BAROMETER 29.80"

APR 3-4, 1913
7.5 HOURS.

TIME.	WATER METER CU. FT.	FEED WATER TEMP. °F.	STEAM PRES. LBS/□"	DRAFTS IN. H_2O			REMARKS.
				OVER FIRE	UNDER DAMPER	BASE STACK	
P.M.							
9:30	405	167	85	.11	.65	.91	STOKER STOPPED
9:45	413	162	115	.00	.31	.53	DAMPER CLOSED REAR DOORS OPEN.
10:00	436	162	110	.06	.28	.82	
10:15	444	152	62	.06	.27	.77	
10:30	-	-	77	.05	.26	.76	
11:00	-	-	93	.05	.27	.76	
11:15	-	-	63	.03	.21	.69	
11:30	-	-	60	.03	.21	.68	
11:45	-	-	60	.02	.18	.63	840# COAL FIRED.
12:00	465	134	60	.03	.16	.62	
A.M.							
1:00	-	-	40	.03	.18	.62	
1:45	498	78	-	-	-	-	
2:00	-	-	20	.02	.16	.46	REAR DOORS CLOSED
3:00	-	-	12	.05	.26	.66	
4:15	-	-	6	.08	.57	.78	DAMPER OPEN
5:00	506	116	85	.09	.61	.79	1380# COAL FIRED TO REACH FULL LOAD.



FLUE GAS
TEMPERATURE
CHART
TEST Nº 8.



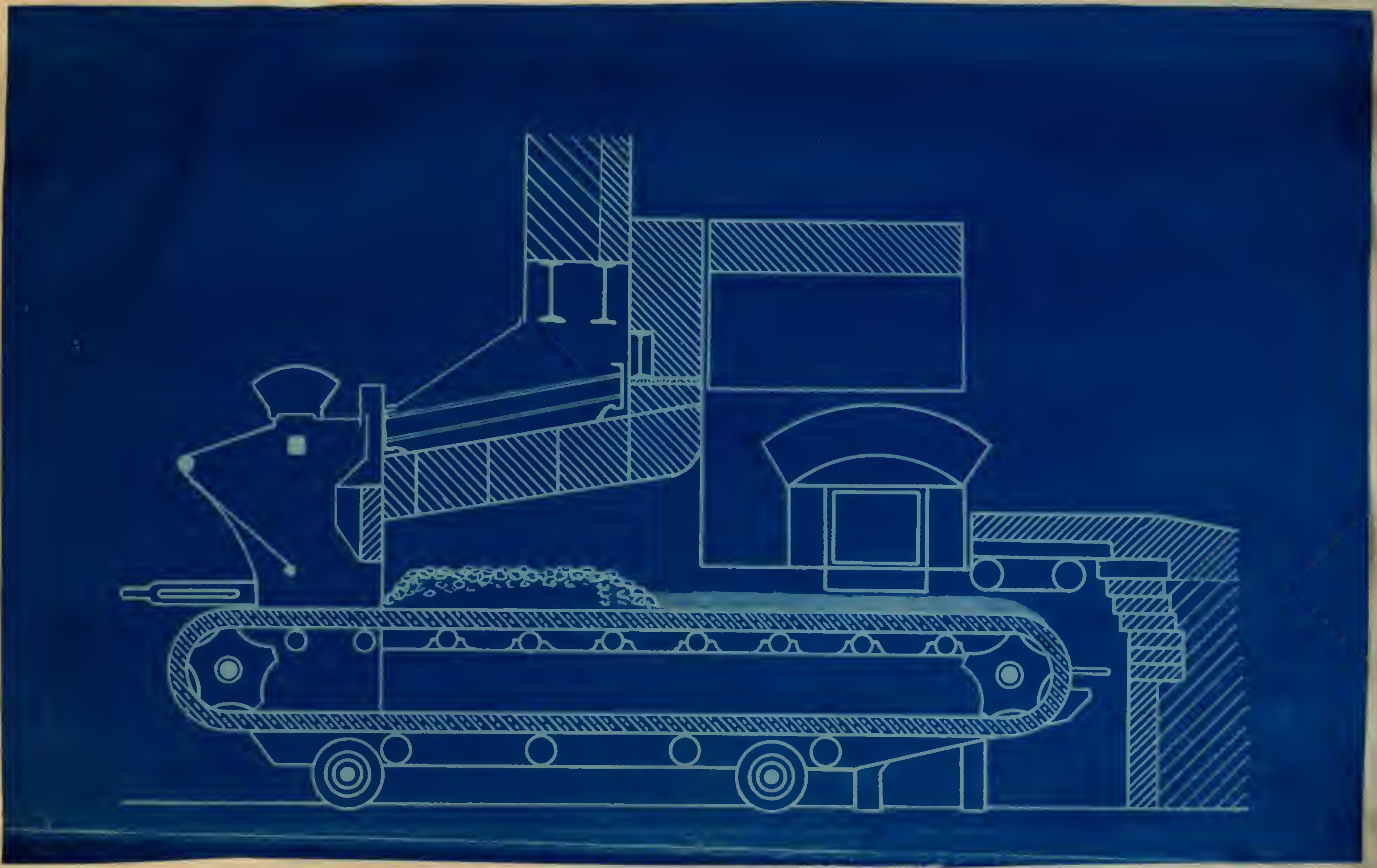
PRESSURE
CHART
TEST Nº 8.

EXPLANATION OF DATA SHEETS.

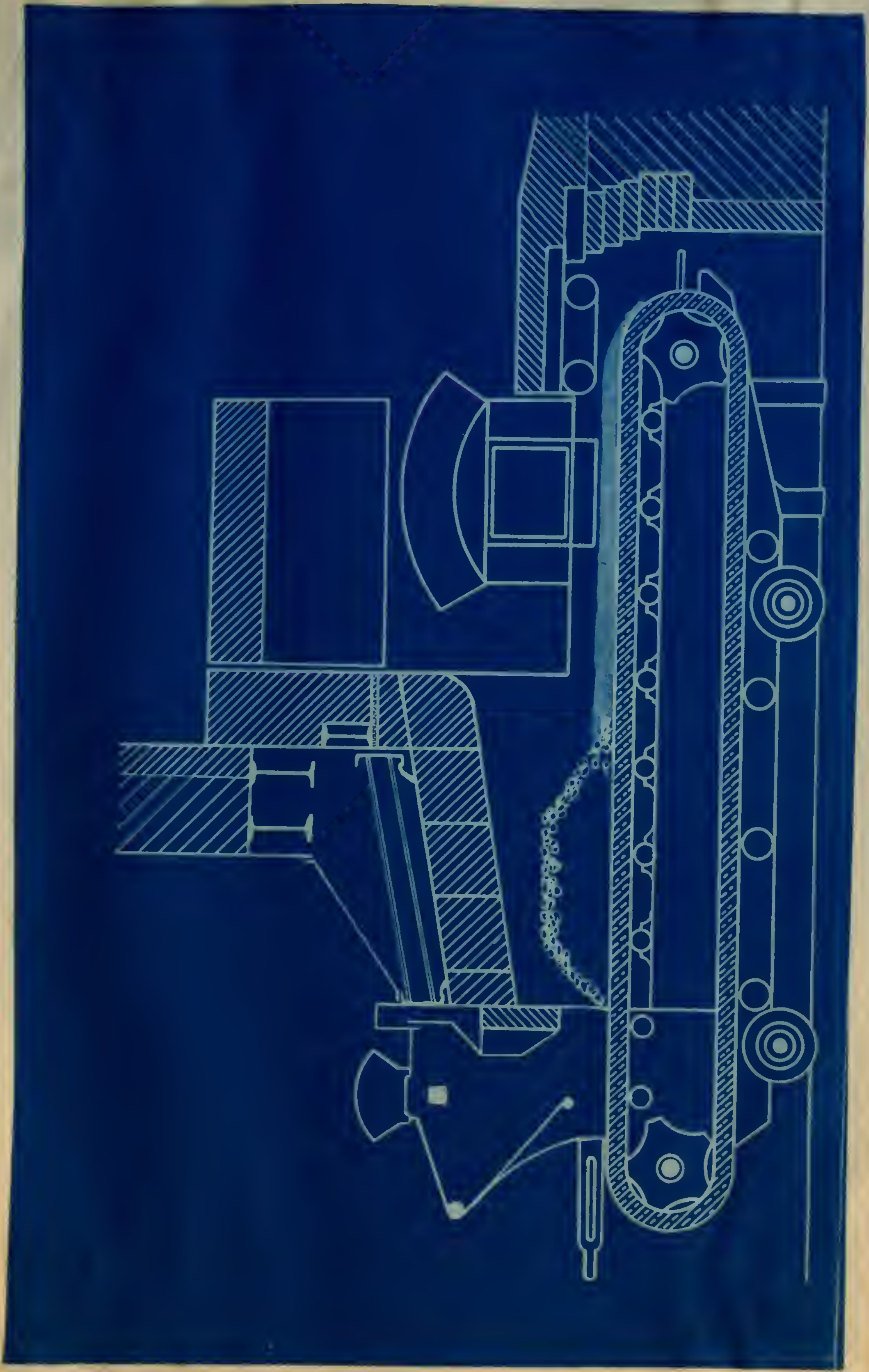
In all the eight tests, three distinct methods of banking the fire were tried. The first, designated as the A.I.T. method, was that of the fireman and consisted merely of adding coal now and then to keep a fire burning in the furnace. The coal added was run in with a fuel bed equal in depth to that at which the stoker gate had been set when the boiler was working at full load. As no attempt was made to exclude the air from the coal, other than merely closing the damper, the rate of combustion was somewhat great for a banking test. Sketch A shows the condition of the fuel bed for this method of banking. The numbers of the test carried out under this method are (1) and (5).

The second method, designated as the A.I.T. (improved), consisted of adding coal as needed, but differed from the first method in the fact that the gate was raised whenever coal was added. This method is illustrated in sketch B. Tests numbered (2) and (6) were carried out in this manner.

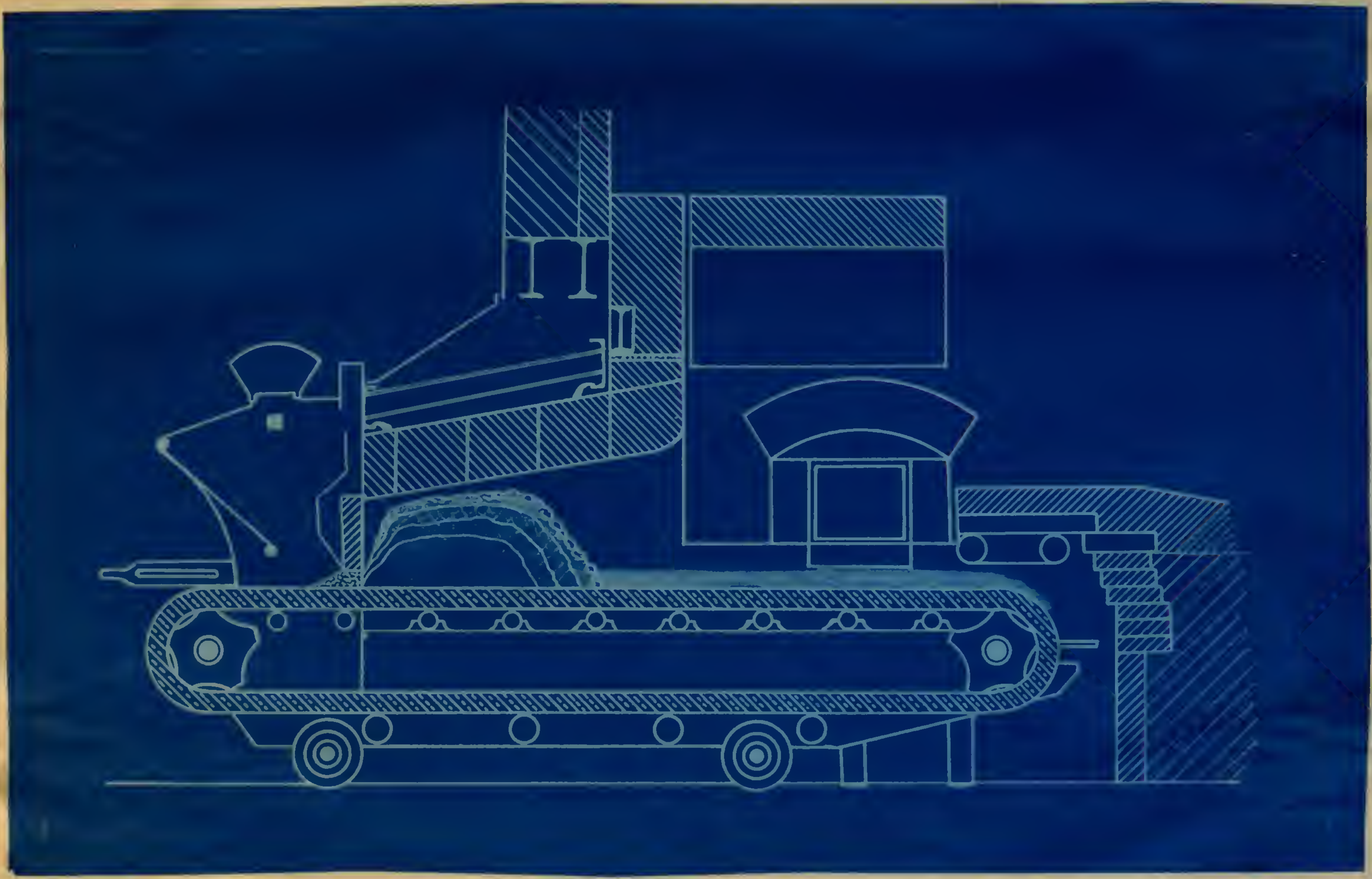
The last method was that recommended by the Green Engineering Co. and is designated GECO. In this method the total amount of coal was thrown into



SKETCH A.



SKETCH B.



SKETCH C.

the furnace at one time, the gate being opened to its maximum and the coal heaped up in the manner shown in sketch C. The draft was cut down as much as possible by closing the damper and opening the doors in the back of the setting. The gate was also lowered after the coal had been put in and the outside was packed with wet ashes, so that there was little chance for air leakage. With this method the coal coked and burned very slowly. The coal run in was estimated to just last until the bank was broken up. Tests numbers (4), (7), and (8) were carried out in this manner.

From the data sheets it can be seen that from the water end some of the tests were absolute failures. In none are the results correct due to the inaccurate methods used to measure the water. In tests numbers (5), (6), (7), and (8), the measurement of water was made under like conditions, so that the results from those tests are comparable. For these tests the factor of evaporation and combined boiler and furnace efficiences were calculated as shown in the appendix.

In all the tests the coal used during the

period from the time the stoker was stopped to the time that the bank was broken up was the finest coal in the bin, which resembled screenings but had the same proximate analysis as the No.2 washed nut. From the time the bank was broken up to the end of the test the regular washed nut was used. The reason for this discrimination in the matter of the size of coal used during these periods was due to the fact that when the fire was banked it was desirous that the coal burn as slowly as possible; in other words, the flow of air through the fuel bed should have been the ~~a~~ minimum, and hence fine coal was fired, while in starting up, where the maximum of combustion was desirable, the washed nut of uniform size was the best. The total coal recorded in the final sheet as having been used during the test is the sum of the fine and the regular size coal that was fired as stated.

The running conditions of the boiler and furnace were the same under all the tests, a bed of six inches depth being carried while the stoker was in operation before the tests. The assumption can be made that the time required from the start

of the test for the existing bed of fuel to burn out was the same in all of the tests, thus eliminating any corrections that would be necessary if the depth of fuel bed had been variable during the different runs.

In determining the water fed to the boiler during the banking period, a string was placed at the level of the water in the gauge glass, a half hour after the stoker had been stopped. The water pumped into the boiler to keep the water level up to this mark till the end of the test was considered, for the sake of comparison, the amount evaporated during the banking period. Undoubtably this amount of water was far too small, due mainly to the fact that when operating under load at the end of the test the apparent water level was above the mean water level, on account of the surging of the water in the tubes leading to the front steam drums. This accounts also for the low efficiencies that have been worked out and have been recorded on the final data sheet.

The manner in which the boiler was considered to be working under full load at the end of the test was very inaccurate. The only method used was

to assume that when the boiler was able to maintain 85 pounds pressure with steam turned into the heating system it was operating at full load. This assumption was not without its merits, for at the end of each test the condition of the furnace was identical with its condition when the boiler had been working under load before the test.

CONCLUSION.

The greatest economy in coal reached in the tests was that of the GECO method, number (7), in which 278 pounds of coal was used per hour of bank. This represents the coal fired during the bank divided by the length of the banking period in hours.

For the minimum time required in coming up to load, the GECO method as shown by test number (8) excelled over the others. The time that was required in this test was 46 minutes.

The test in which the greatest efficiency during the banking period was reached was number (5).

In comparing the tests from the viewpoint of commercial efficiency, the GECO method, as illustrated in tests numbers (7) and (8), is by far the better. Even though the efficiency for these

tests were low in comparison with the results reached in some of the other tests, a good efficiency was not of the highest importance, although it was desirable. What was important was to lower the cost of operation during the banking period as low as possible. This the GECO method did, for,besides effecting a saving over the other methods in coal and in the time required to come up to capacity, it excelled also in the fact that after the coal was once put in the furnace for the bank, no furthur attention was needed until the bank was broken. In banking with this method the saving in coal over the other ways would be an appreciable amount yearly.

APPENDIX

Method of Calculating Results.

Test No.(6).

7.5 hours duration.   Total coal 2400 pounds.

Coal per hour 320 pounds.

Water metered-

156 cu. ft. at 167.6°F.	9770#
19 cu. ft. at 152°F.	2975#
15 cu. ft. at 88°F.	1368#
Total Water Evaporated	14, 113 lbs.

156 x 167.6 = 26,145.6

19 x 152 = 2978

15 x 88 = 1320

190 cu.ft.   30,343.6

$$\frac{30,343.6}{190} = 149^{\circ}\text{F. mean temperature of feed water.}$$

Since the value of the total heat(H)of a pound of steam varies almost directly as the pressure The value of (H) in the calculations was taken as that corresponding to the mean pressure.

Mean gauge pressure- 46.5 #

Barometric pressure- 14.36#

60.86 # abs.

For this pressure (H) equals 1177.2.

$$\text{Factor of Evaporation} = \frac{1177.2 - 149\ \ 32}{970.4} = 1.093$$

$$\frac{14,113}{2400} = 5.89 \text{ pounds of water apparently evaporated per pound of coal.}$$

5.89 x 1.093 = 6.44 the equivalent evaporation.

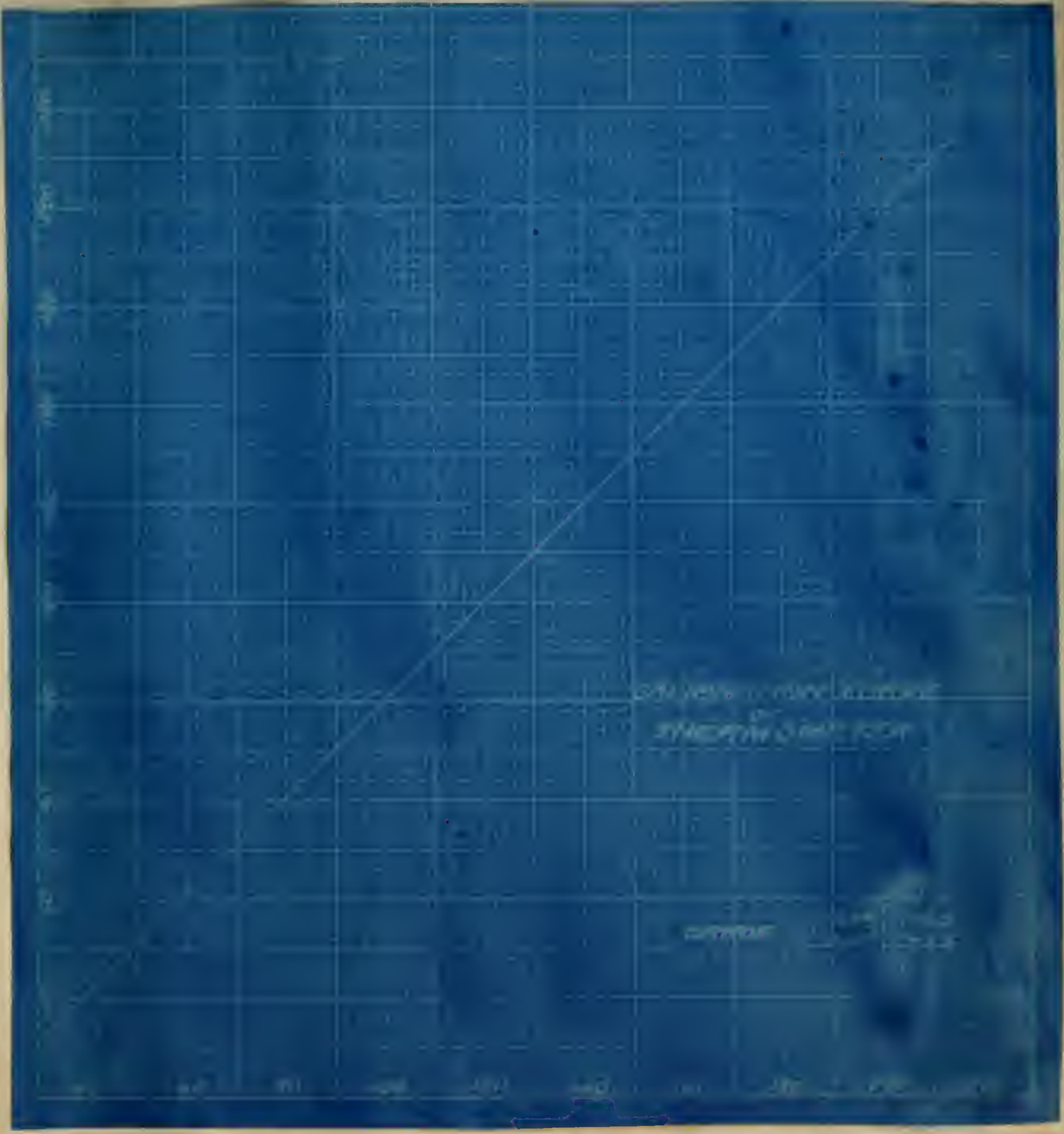
As there was no method of measuring the ash of the coal burned during the banking period, the following efficiency is that which is recorded in the final data sheet.

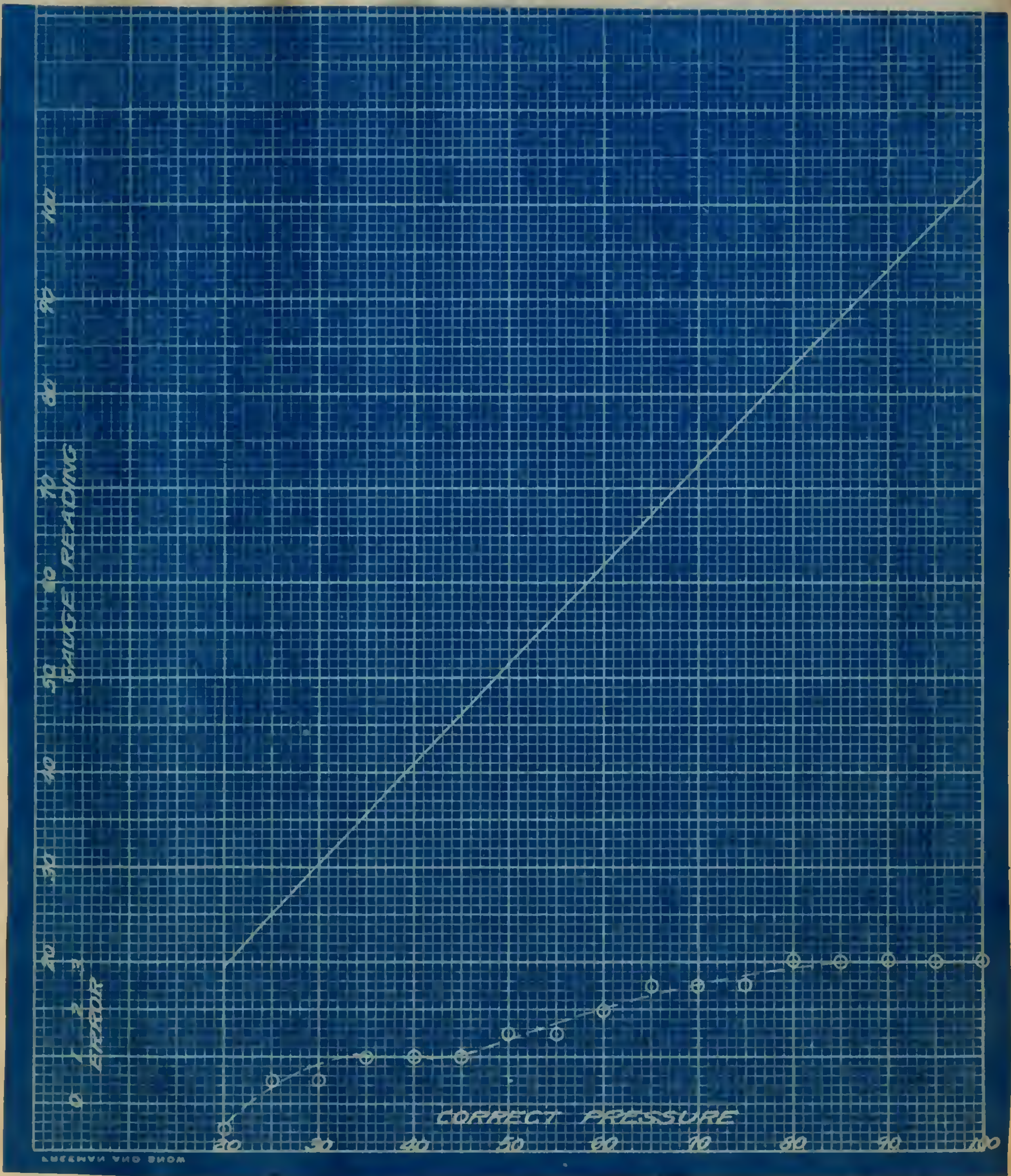
$$\text{Efficiency} = \frac{\text{B.T.U. absorbed by Boiler per pound of coal fired}}{\text{B.T.U. value of coal as fired}}$$

In this case

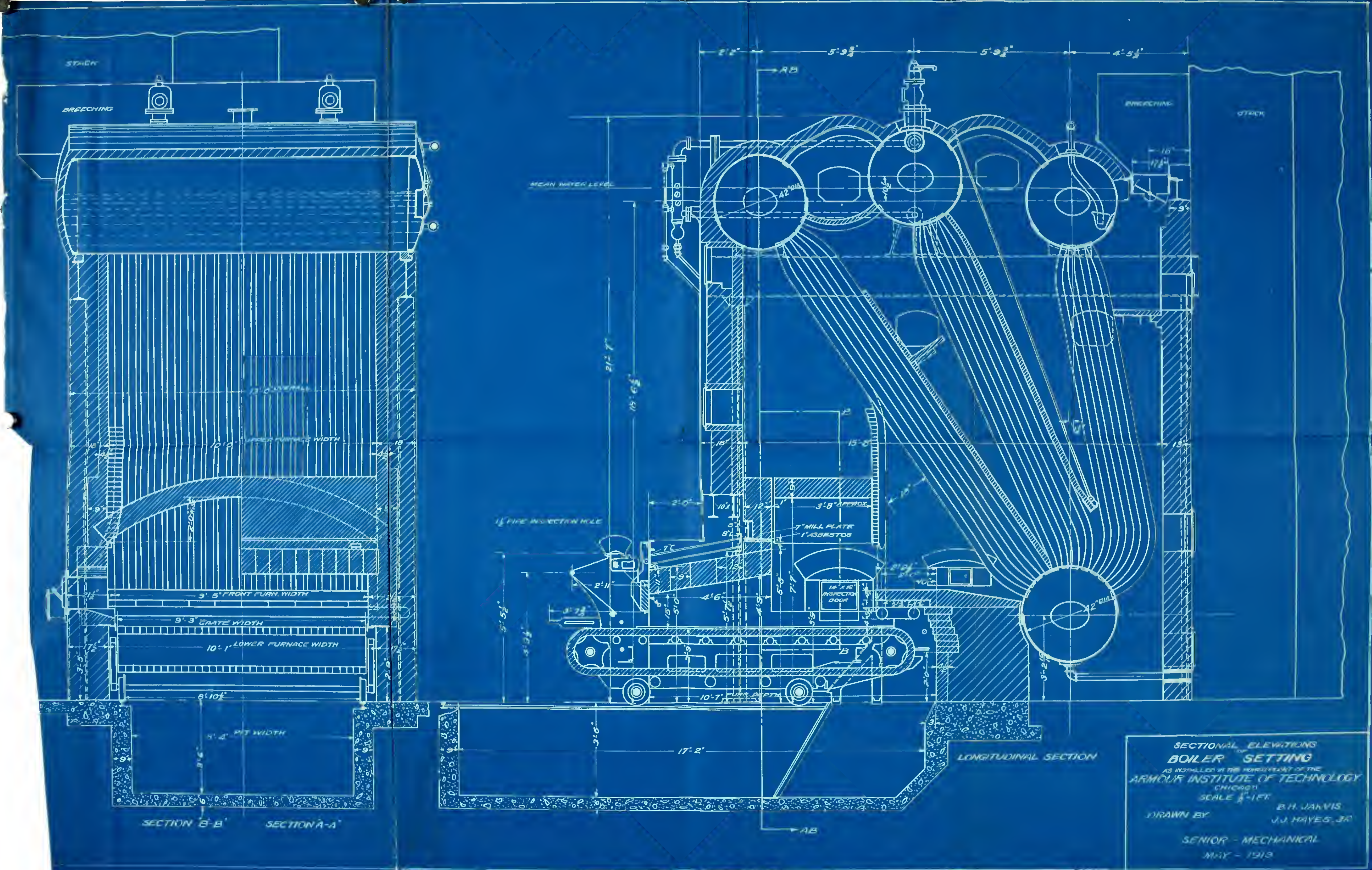
$$\text{Efficiency} = \frac{6.44 \times 970.4}{13,500} = 46.3\%$$

This efficiency is the overall efficiency of the boiler and furnace.





CALIBRATION CURVE
OF
PRESSURE GAUGE



SECTIONAL ELEVATIONS
OF
BOILER SETTING
AS INSTALLED IN THE POWERPLANT OF THE
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO
SCALE ½"-1 FT.

DRAWN BY
B.H. JARVIS
J.J. HAYES, JR.

SENIOR - MECHANICAL
MAY - 1913